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REPORT OF COOPERATIVE RESEARCH ON INSECT CONTROL IN FARM STORED GRAIN

No. 13 Period--July 1 to September 30, 1944

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The material in this report consists largely of unpublished data ~~and should be kept confidential~~. It is made available in its present form for the convenience of the various State and Federal Agencies concerned with the preservation of stored grain from insect damage.

Declassified Memo 6/9/54 KP 6/10/54

WHEAT STORAGE

Effect on Different Management Practices on Insect Populations in Wheat Stored in Ever-Normal Granary Type Bins*

One of the primary objectives of the wheat storage work has been the determination of the effect of the different management practices on the insect populations in stored grain. When the project was started in the summer of 1941, a group of bins was designated as the management series. The grain in this series of bins received different treatments with the object of determining the best and cheapest method of handling grain stored in Commodity Credit Corporation type bins. This work has now been in progress for a period of three years, and as a result, differences between management practices have become apparent. The status of the management series as of September 30, 1944, is given in the following tabulation:

* -- Reported by H. H. Walkden and R. B. Schwitzgebel, U. S. Dept. of Agriculture, Bureau of Entomology and Plant Quarantine in cooperation with the Bureau of Plant Industry, Soils, and Engineering.

Grain Storage Practice	Original Number of Bins in Series	Number Remaining September 30, 1944
1. Fumigation in August and October	11	10*
2. Turning, cleaning and fumigating in September	3	3
3. Walls and roofs painted white	5	5
4. White walls and roofs, grouped for shading	4	4
5. Fumigation in September	8	8
6. No treatment, 9-10% moisture grain	2	2
7. " " 10-11% " "	8	2
8. " " 11-12% " "	21	0
9. " " 12-12½% " "	4	0
10. " " 12½-14% " "	5	0
11. Turning in January	10	0
12. Turning and cleaning when necessary	7	0
13. Oil spray on surface, June and August	9	0
Totals	97	34

The basis for elimination was the development of dangerous insect populations in the grain.

* - Note: One bin in this series was eliminated because of roof-leaks, and not because of the failure of the treatment.

From the above tabulation it may be noted that treatments 1 to 5 gave equally good protection from insect damage. The grain in these groups was of about 11.5 percent moisture content. Grain of 9-10 percent moisture content (treatment 6) has not as yet developed serious insect infestation. Of the 8 bins in the 10-11 percent moisture groups, 6 became dangerously infested with insects and had to be fumigated. The bins in groups 8, 9, and 10 became infested, the rate of development of the population being proportional to the moisture content. The practices of turning in cold weather, turning and cleaning when necessary, and oil spray on the surface, all failed to give protection from insect attack.

Study of the Fluctuation of Insect Populations in Wheat Stored in Ever-Normal Granary Type Bins

The study of insect population fluctuations in wheat stored in ever-normal granary type bins was continued during the past three months. Five-probe samples were taken semi-monthly from the upper southwest quadrant of 49 bins in the management series and a record made of the number of each species of stored grain insects. A summary of the data obtained during the past nine months is presented in table 1 and arranged to show the effect of different grain storage practices on insect populations.

For the purpose of this table the lesser grain borers and the rice weevils were considered as "weevils" and all other species were combined as "bran bugs". The rice weevil was rarely taken in the samples while the principal bran bug species were the flat grain beetle and the sawtooth grain beetle.

It may be noted in table 1 that all grain of 10.5 percent in moisture or greater required treatment during August and September because of severe insect infestation unless it was stored in bins which were painted white. Grain of 9 percent moisture as well as that stored in white steel bins has failed to develop serious insect populations so far this season. The lesser grain borer has been conspicuously absent in white 2740-bushel steel bins.

The data indicate that fumigation in August and October tends to keep the insect population at a lower level than one fumigation in September. The greatest insect populations were recorded in wheat in 2740-bushel steel bins which are turned, cleaned, and fumigated annually in September.

The development of insect infestations in wheat stored in wood bins has been much slower as compared with that in steel bins.

Grain in wood bins painted red has had higher populations than wheat in wood bins with white walls. Painting the roof of a wood bin white in addition to the walls tends to keep the lesser grain borer populations at a very low level.

Several 2740-bushel steel bins were filled with wheat from Haven, Kansas, Coop Elevator when the Hutchinson site was established in June, 1941. This wheat was drier than that used to fill the remaining bins, testing about 10.9 percent moisture. Two lots of this grain (bin 5-1 and 6-2) were set aside as untreated checks. Several other bins were given an initial fumigation with no further treatment planned. Although most of the other 2740-bushel lots of grain on the site developed heavy insect infestations and required treatment by the fall of 1942, the insect populations in these bins of dry grain remained at a very low level.

To demonstrate the effect of temperature on insect development one 2740-bushel lot of this Haven wheat (5-2) was divided among three 1000-bushel steel bins, (1-5, 4-10, 4-11) in May, 1944. Observations on the insect populations in these bins were continued until September 1, 1944, at which time all of the bins required fumigation because of insect infestation.

The results of these observations are presented in table 2. It may be noted that about five times as many lesser grain borers and more than three times as many bran bugs were found in the 1000-bushel lots of grain than were taken in the 2740-bushel bins by September 1. With no change having occurred in the moisture content of the wheat the change in temperature conditions must have been responsible for the differential rate of insect development which was effected by reducing the size of the storage units. On September 1 the grain in the upper southwest quadrant of the three 1000-bushel lots of grain averaged 83° F.; while in the same region of the 2740-bushel bins the average temperature was 76° F.

In order to study the effect of moisture on insect development six 1000-bushel steel bins were filled with wheat from the 1943 crop shortly after harvest of that year. Two lots of grain were secured for each of three moisture contents -- 9.3 percent, 11.3 percent, and 12.0 percent. Observations were made to determine insect populations in these bins and these data are presented in table 3.

It may be noted from table 3 that the development of insects was most rapid in the grain of the highest moisture content and slowest in the driest grain. The effect of higher moisture content on the rate of increase of the bran bug population is more pronounced than for the lesser grain borer.

Table 1:--Summary of the insect populations in the upper southwest quadrant of steel and wood bins, Hutchinson, Kansas, 1944.

Grain storage practice	Jan. 11	Feb. 10	Apr. 1	June 3	July 1	July 15	Aug. 1	Aug. 15	Sept. 1	Sept. 15
	Average number of insects per 1000-grams.									
1000-bushel steel bins										
No treatment:										
9.3% moisture	0'	0	0	0	0.2	0.2	0.4	0.8	1.8	2.4
	0''	0	0	0	0.6	0.6	1.8	1.0	1.8	0.4
10.8% moisture				0	0	1.2	5.6	7.6	14.8 F	(Termi-
				0	3.2	5.2	12.8	9.2	9.2	nated)
11-11.5% moisture	5.2	0.6	0.1	0.2	0.3	1.5	6.0	6.0	43.5	10.3
	6.8	32	1.6	5.8	11.4	20.0	40.8	20.6	57.2*	29.3**
12% moisture	0.6	0	0	0	0	1.4	4.8	4.2	11.8	(Termi-
	1.9	10.7	0.4	0	2.0	8.6	18.0	33.0	53.2 F	nated)
White walls and roof	0	0	0	0	0	0.2	0	0	3.6	1.0
	2.0	0.5	0	1.8	1.6	1.4	3.6	5.6	17.4	10.4
Fumigation in September	0	0	0	0	0	0.4	2.8	8.2	24.2 F	0.4
	1.2	0.4	0	0	0.2	3.6	12.6	22.4	82.8	0.8
Fumigation in August and October	0	0	0	0	0	1.5	2.0	3.3 F	0.2	0.3
	0	0.1	0	0	2.2	6.5	8.7	11.6	0.3	0.8
Turn, clean, and fumigate in September	0.2	0	0	0	0	0.4	4.4	2.4	8.8 T	2.0 F
	0.6	0.4	0	0.4	0	3.6	6.8	11.2	19.2	1.2
2740-bushel steel bins										
No treatment										
10.5-11% moisture	0.7	0.2	0.0	0.0	0.2	0.3	2.2	3.8	10.5 F	(Termi-
	0.6	0.5	0.1	0.6	1.5	10.7	11.1	20.2	21.2	nated)
11-11.5% moisture			0.0	0.0	0.2	1.2	3.7	2.6	9.8 F	Termi-
			0.2	0.9	2.3	2.7	5.4	7.5	19.8	nated)
White walls and roof	0	0	0	0	0	0	0	0	0	0
	1.9	0.3	0.5	0.5	0.1	0.6	3.3	8.8	7.2	5.9
Painted white and grouped for shading	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
	2.0	1.8	0.5	0.6	0.6	1.1	2.2	1.4	4.0	2.3

Table 1 (concluded)

Grain storage practice	Jan. 11	Feb. 10	Apr. 1	June 3	July 1	July 15	Aug. 1	Aug. 15	Sept. 1	Sept. 15
	Average number of insects per 1000-grams.									
Fumigation in September		-	0	0	0.1	0.2	1.0	3.2	7.5 F	1.2
			1.8	0.3	4.6	2.7	5.8	9.3	11.8	1.8
Fumigation in August and October	0	0	0	0	0	1.1	1.1	5.5 F	0	0.2
	0	0	0	0	0	0.6	2.2	11.0	0	0.2
Turn, clean, and fumigate in September	0	0	0	0	0.5	0.7	6.3	11.7	61.4 T	3.5 F
	2.7	1.0	3.6	0.2	13.5	32.6	87.9	33.2	80.9	14.9
1500-bushel wood bins										
White walls and roof	0	0	0	0	0	0	0	0	0	0.6
	2.0	0.8	0	0	1.0	2.8	10.4	21.6	21.2	31.0
White walls	0	0	0	0	0	0	0.2	2.8	0.6	4.0
	2.0	0.4	0	0	1.2	4.4	7.3	12.4	47.2	19.8
Red walls	3.0	0	0	0.2	0.2	0	1.2	4.6	2.8	6.6
	4.0	1.6	0.4	0.2	6.8	11.8	55.0	62.0	60.4	58.8

' = Weevils: includes lesser grain borer and rice weevil

'' = Bran bugs: all species except the weevils

* = Fumigated two of six bins

** = Fumigated two of four remaining bins

F = Grain fumigated

T = Grain turned and cleaned

Table 2:--Effect on insect populations resulting from the transfer of grain from 2740 to 1000-bushel bins, Hutchinson, Kans. 1944

Bin number	Average number of insects per 1000 grams June 3	July 1	July 15	Aug. 1	Aug. 15	Sept. 1
			1943			
Average of 5-1	0'	0	0.2	0.1	3.0	6.2
and 6-2	4"	3.0	8.4	16.0	12.1	15.0
5-2	0	0	0	0.8	3.0	2.0
	2.0	4.0	7.0	11.4	10.0	7.0
			1944			
Average of 5-1	0	0	0.4	1.1	3.0	11.7
and 6-2	1.2	2.0	16.5	13.0	19.0	15.0
Average of 4-10,	0	0.3	0.9	5.3	9.7	55.0
4-11 and 1-5 *	0.6	7.7	10.3	30.3	21.0	50.0

' = Lesser grain borer
" = Bran Bugs
* = Grain from 5-2

Table 3:--Comparison of insect populations in wheat of three different moisture contents stored in 1000-bushel steel bins, Hutchinson, Kans. 1944.

Bin number	Moist. (%)	Average number of insects per 1000 grams Apr. 1	June 3	July 1	July 15	Aug. 1	Aug. 15	Sept. 1	Sept. 15
Ave. of $\frac{1}{2}$-3	9.3	0'	0	0.2	0.2	0.4	0.8	1.8	2.4
and $\frac{1}{2}$-6		0"	0	0.6	0.6	1.8	1.0	1.8	0.4
Ave. of 2-14	11.3	0	0.2	0.4	0.2	3.0	2.0	17.0	8.0
and 11-12		0	0.2	1.0	1.2	3.4	0.6	14.2	7.4
Ave. of $\frac{1}{2}$-9	12.0	0	0	0	1.4	4.8	4.2	11.8	Fumigated
and $\frac{1}{2}$-10		0.4	0	2.0	7.6	18.0	33.0	43.2	

' = Lesser grain borer
" = Bran bugs

Control of Insects in Farm-stored Grain

As indicated in Report No. 12, work was started on the control of insects in farm-stored grain. During the past three months, frequent observations have been made to determine the effectiveness of the various interior wall treatments, which were applied before the bins were filled with wheat of the 1944 crop. Samples were taken at the surface of the grain next to the wall and from the grain mass.

The infestation was determined from the examination of these samples. The results are given in table 4. From the table it may be noted that the greatest number of dead insects were found near the walls which had been treated with DDT, and also that the intensity of infestation varied greatly in the different bins. Large numbers of dead cadelles were observed on the surface of the grain adjacent to the walls treated with DDT, and extended out about 18 inches from the wall. Very few dead insects were noted on the surface near walls receiving other treatments. It was also noted that cadelle larvae were scaling off the whitewash near old burrows, and in some instances were entering them. The insect infestation in the grain mass was negligible in all of the granaries.

The comparative abundance of the species of stored grain insects found in the farm bins is given below:

Species	Percent
Cadelle (*Tenebroides mauritanicus* L.) larvae	66.6
Cadelle adults	1.3
Flat grain beetle (*Laemophloeus minutus* Oliv.)	19.2
Lesser grain borer (*Rhyzopertha dominica* Fab.)	4.1
Sawtooth grain beetle (*Oryzaephilus surinamensis* L.)	3.2
Rice weevil (*Sitophilus oryza* L.)	2.2
Red flour beetle (*Tribolium castaneum* Hbst.)	1.3
Small-eyed flour beetle (*Palorus ratzeburgi* Wissm.)	0.9
Dermestid larvae (*Trogoderma* sp.)	0.6
Foreign grain beetle (*Ahasverus advena* Waltl.)	0.3
Yellow meal worm larvae (*Tenebrio molitor* L.)	0.3

From the above tabulation it may be seen that the cadelle is by far the most abundant insect in farm-stored grain. In addition to the work with wall treatments, a number of farm granaries were fumigated experimentally. The results are presented later in this report.

Table 4:—Effect of various wall treatments on insect infestation in farm-stored grain, Reno County, Kans. September 1944.

Location	Wall treatment	Number of insects per 1000 grams Surface sample next to wall Living	Dead
Oldenettel West bin	Whitewash	96	4
	Red barn paint	48	0
	White lead paint	42	4
	Dendrol-lye	42	58
	DDT	10	70
Oldenettel East bin	K-655	12	0
	Untreated check	10	0
	Dendrol-lye	8	4
	K-1127	6	0
	K-208	6	0
	Deobase oil	4	2
	DDT	4	32
Swanson granary	Untreated check	12	0
	Deobase oil	6	0
	DDT	4	0
Swanson, west box car	Dendrol-lye, south wall	42	4
	Dendrol-lye, west wall	16	0
	Dendrol-lye, east wall	14	0
Swanson, east box car	DDT, west wall	6	0
	DDT, south wall	4	0
	DDT, east wall	2	0
	DDT, north wall	0	0
Bacon SE bin	K-655	16	0
	Deobase oil	12	0
	K-208	6	0
	K-1127	2	0
	Untreated	2	0
Gump	DDT	6	0
	Red barn paint	4	0
	White lead paint	2	0
	Whitewash	0	0

The composition of the various materials is given in Report No. 12.

Experimental Fumigation of Wheat

During the past three months some 90 bins, aggregating nearly 140,000 bushels of grain, have been fumigated experimentally. With the discovery that fumigants are retained in killing concentrations for long periods in grain stored in tight steel bins, it was thought advisable to evaluate the efficiency of certain compounds formerly considered to be of too low toxicity for use in grain fumigation. The compounds which were included in the tests are listed below:

Compound	Density	Boiling point deg. C.	Cost per lb. cents
Trichlorethane	1.44	113	18.75
Tetrachlorethane	1.588	131	8.
Trichlorethylene	1.46	87	8.4
Tetrachlorethylene	1.623	121	9.
Dichloromethane (methylene chloride)	1.336	40	16.7
Tetrachloromethane (carbon tetrachloride)	1.595	76	8.
Dichloroethylether	1.17	178	-

In addition to the above materials, ethylene dibromide was tested as a surface toxicant and several commonly used mixtures were tried in farm granaries. The results of the experimental fumigation work is given in table 5. The average kills for the various fumigants is given at the end of the table.

1. Experimental fumigation of grain stored in steel bins (Table 5, Part 1)

   Trichlorethane and tetrachlorethane failed to give good kills at dosages of 3 gallons per 1000 bushels. Further, these materials imparted an odor to the grain which persisted for more than two months. This quality precludes their use as grain fumigants.

   Trichlorethylene gave good kills at dosages of 3 gallons per 1000 bushels in both the test probes and in the natural populations. As a result of these trials, it is felt that this material can be used satisfactorily as a grain fumigant and the cost is about the same as for the commonly used fumigants.

   Methylene chloride (dichloromethane) gave insufficient kills at a dosage of 2 gallons per 1000 bushels. At 3 gallons per 1000 bushels the kills in test probes were good, but at its present cost it cannot compete with other materials.

   Carbon tetrachloride continues to give excellent results both in test probes and in natural populations even at dosages of 2 gallons per 1000 bushels. From the standpoint of cost, safety and efficiency it approaches the ideal grain fumigant.

Dichloroethylether was tried in one bin. While the kill was satisfactory, this material imparted a very strong odor to the grain which has persisted for nearly 3 months, a quality which rules it out as a grain fumigant.

The 3:1 mixture of ethylene dichloride-carbon tetrachloride, used as checks in two bins, gave good results at 2 gallons per 1000 bushels. However, past experience indicates that 4 gallons per 1000 bushels is required for consistently good kills.

In cooperation with the Dow Chemical Company, ethylene dibromide was tested as a surface toxicant, using carbon tetrachloride as a carrier. A mixture consisting of 10% ethylene dibromide, carbon tetrachloride 90% gave better kills in the surface grain than did the mixture containing 5% ethylene dibromide at a dosage of 2 gallons per 1000 bushels. The ethylene dibromide appears to be thrown out in the top foot of grain and remains effective for at least a week. This mixture shows great promise, inasmuch as the weakness with carbon tetrachloride alone has been its failure to kill in the surface grain.

Ethylene dibromide was also tested in combination with the 3:1 mixture of ethylene dichloride-carbon tetrachloride. The results were no better than when it was used with carbon tetrachloride.

A mixture consisting of carbon tetrachloride, 90%; methyl bromide, 5%; and ethylene dibromide, 5% gave excellent results at a dosage of only 1 gallon per 1000 bushels.

2. Experimental fumigation of grain stored in wood Ever-Normal Granary bins and wood farm granaries.

Through the cooperation of farmers in Reno County, many farm granaries were made available for experimental fumigation. When it is considered that the amount of grain stored on the farm averages about three hundred million bushels, the importance of an efficient stored grain insect control program for farm-stored grain can hardly be over-emphasized.

In an attempt to determine minimum dosages of fumigants for farm bins, a series of farm granaries was fumigated during the quarter. The bins chosen for fumigation varied from very loose, poorly built structures to those which were well built and as tight as a wooden bin can be made. The results with the various fumigants in the different farm bins are given in table 5, part 2.

Altogether, the results were surprisingly good. However, in some bins which appeared to be fairly tight, poorer results were obtained than in others which seemed to be loose. From these results it is quite probable that somewhat higher dosages will be required for wood farm bins than for steel bins. Further fumigation of farm-stored grain is planned to establish definitely the dosages required for the many different types of granaries in use.

Table 5: -- Experimental fumigation of grain, Hutchinson, Kans. 1944

PART I. STEEL BINS

Fumigant	Bin No.	Capacity (bu.)	Date treated	Dosage per 1000 bu.	Percent mortality: Test probes	Percent mortality: Natural population
Trichlorethane	10-7	2000	7/19	3	78	--
	8-10	2740	7/19	3	73	--
	9-5	2740	7/19	3	81	--
Tetrachlorethane	10-8	2000	7/19	3	66	--
	10-4	2740	7/19	3	79	--
	12-7	2740	7/19	3	83	--
Trichlorethylene	2-14	1000	9/19	2	99	65
	4-11	1000	9/19	2	98	81
	11-12	1000	9/19	2	99	74
	½-10	1000	9/5	3	100	96
	1-5	1000	9/5	3	87	97
	8-12	1000	7/19	3	100	--
	5-4	2740	7/19	3	100	--
	6-4	2740	7/19	3	100	--
Tetrachlorethylene	4-13	1000	7/19	3	99	--
	9-4	2740	7/19	3	91	--
	7-11	2740	7/19	3	80	--
	8-6	2740	9/5	3	45	88
	7-7	2740	9/5	3	56	91
Methylenechloride (dichloromethane)	2-16	1000	9/5	2	53	14
	4-11	1000	9/5	2	72	37
	6-2	2740	9/5	2	85	67
	8-3	2740	9/5	2	67	92
	1-1	1000	7/19	3	100	--
	6-3	2740	7/19	3	100	--
	5-5	2740	7/19	3	91	--
Carbon tetrachloride (tetrachloromethane)	Walsten	500	8/11	2	91	--
	Walsten	800	8/11	2	99	--
	Judy	1000	8/18	2	95	--
	3-13	1000	9/12	2	--	97
	4-12	1000	9/12	2	--	98
	11-2	2740	9/12	2	--	93
	12-2	2740	9/12	2	--	91

Table 5, continued

Fumigant	Bin No.	Capacity (bu.)	Date treated	Dosage per 1000 bu.	Percent mortality: Test probes	Percent mortality: Natural population
Carbon tetrachloride (continued)	11-10	2740	9/12	2	--	97
	11-11	2740	9/12	2	--	97
	7-3	2740	9/12	2	--	80
	7-4	2740	9/12	2	--	94
	4-16	1000	7/19	3	100	--
	5-3	2740	7/19	3	100	--
	5-8	2740	7/19	3	100	--
Dichloroethylether	3-15	1000	7/19	3	90	--
Ethylene dichloride 75%-carbon tetrachloride 25%	3-12	1000	8/11	2	89	100
	2-12	1000	8/11	2	96	97
	3-14	1000	9/20	4	--	100
	5-7	2740	9/20	4	--	99
	6-11	2740	9/20	4	--	99
Carbon tetrachloride 90%-ethylene dibromide 10%	4-10	1000	9/5	2	99	99
	½-9	1000	9/5	2	100	99
	8-2	2740	9/5	2	100	99
	5-1	2740	9/5	2	99	100
Carbon tetrachloride 95% - ethylene dibromide 5%	1-16	1000	8/11	2	100	--
	1-1	1000	8/11	2	99	--
3:1 mixture of ethylene dichloride and carbon tetrachloride 95%-ethylene dibromide 5%	1-2	1000	8/11	2	96	--
	4-16	1000	8/11	2	95	--
Carbon tetrachloride 90% - ethylene dibromide 5%--methyl bromide 5%	2-16	1000	8/11	1	93	--
	Swanson	900	8/11	1	98	89

Table 5 (continued)

PART II. WOOD BINS

Ever-Normal Granary and Farm Granaries. (Ever-Normal Granary bins are indicated by an asterisk.)

Fumigant	Bin No.	Capacity (bu.)	Date treated	Dosage per 1000 bu.	Percent mortality: Test probes	Percent mortality: Natural population
Trichlorethylene	O'Neal	700	8/30	3	94	--
	O'Neal	1200	8/30	3	54	--
	Swanson	1300	8/30	3	67	30
Methylene chloride	Swanson	1300	8/30	3	56	40
Carbon tetrachloride	13-3 *	1500	9/19	2	99	--
	13-4 *	1500	8/11	2	89	--
	13-4 *	1500	9/19	2	97	--
	387 *	1500	8/11	2	94	--
	Goodenough	500	9/6	3	44	38
	Walsten	500	8/23	3	87	--
	Walsten	500	8/23	3	88	--
	Albright	700	8/23	3	83	--
	Walsten	1000	8/23	3	97	--
	Burling	1000	8/19	3	100	--
	Burling	1400	8/19	3	100	--
	Burling	1400	8/19	3	100	--
	Burling	1400**	8/19	3	100	--
	Hayworth	1500	9/6	3	93	--
	Burling	1700	8/22	3	100	--
	Burling	1700	8/22	3	77	--
	Burling	1800	8/22	3	56	--
	Burling	3000	8/22	3	95	--
	Henderson	1000	9/6	3	88	--
	Henderson	1000	9/6	3	48	--
Carbon tetrachloride 80% - carbon disulphide 20%	Swanson	500	8/23	3	67	100
	Walsten	700	8/23	3	88	--
	Swanson	1000	8/23	3	86	95
Carbon tetra-chloride 25% - ethylene dichloride 75%	Goodenough	500	9/6	6	100	100
	Judy	500	8/15	8	100	--
	Judy	500	8/15	8	99	--
	Judy	750	8/15	6	100	--
	Judy	750	8/15	6	100	--
	Judy	1000	8/15	6	97	--
	Henderson	1000	8/19	6	81	--
	Henderson	1000	8/19	6	64	--
	Hayworth	2000	9/6	6	100	--

Table 5, concluded

Fumigant	Bin No.	Capacity (bu.)	Date treated	Dosage per 1000 bu.	Percent mortality: Test probes	Percent mortality: Natural populations
Carbon tetrachloride 95% - ethylene dibromide 5%	336*	1500	8/11	2	98	--
	13-3*	1500	8/11	2	96	--
STEEL BINS		No. of bins			Average Mortality	
Trichlorethane		3		3	77	--
Tetrachlorethane		3		3	76	--
Trichlorethylene		3		2	99	73
do		5		3	97	97
Tetrachlorethylene		5		3	74	90
Methylene chloride		4		2	69	53
do		3		3	97	--
Carbon tetrachloride		11		2	95	92
do		3		3	100	--
Dichloroethylether		1		3	90	--
Carbon tetrachlorice 90%) ethylene dibromide 10%)		4		2	99	99
Carbon tetrachloride 95%) ethylene dibromide 5%)		2		2	99	--
Ethylene dichloride 75%) carbon tetrachloride 25%)		2		2	93	99
		3		4	--	99
3:1 mixture of ethylene) dichloride and carbon) tetrachloride 95%) ethylene dibromide 5%)		2		2	96	--
Carbon tetrachloride 90%) methyl bromide 5%) ethylene dibromide 5%)		2		1	96	89
WOOD BINS						
Trichlorethylene		3		3	72	30
Methylene chloride		1		3	56	40
Carbon tetrachloride		4*		2	95	--
do		16		3	85	--
Carbon tetrachloride 80%) carbon disulphide 20%)		3		3	80	98
Ethylene dichloride 75%) carbon tetrachloride 25%)		7		6	92	--
		2		8	99	--
Carbon tetrachloride 95%) ethylene dibromide 5%)		2*		2	97	--

* = Ever-Normal Granary bins.
** = Bin filled with oats.

In order to obtain information on the rapidity with which carbon tetrachloride penetrates the grain mass in lethal concentrations in wood granaries, a series of check boxes containing living insects were placed in the center of a 1500 bushel wood bin. This bin had been lined with a waterproof paper before filling. The grain in the bin was 10 feet deep and the check boxes were located at the six-foot, three-foot, and floor levels. Three gallons of carbon tetrachloride per 1000 bushels were sprayed on the surface; one check box from each level was removed at hourly intervals for the first seven hours after fumigation and counts made of living and dead insects.

The results of this experiment are presented in table 6. It may be seen that a complete kill was effected at the six-foot level (4 feet below the surface of the grain) within one hour after treatment. After two hours had elapsed nearly all the insects were dead at the three-foot level (7 feet below the surface). About four hours were required to give an adequate kill of the insects located at the floor level.

Table 6: -- Rate of penetration of carbon tetrachloride in grain stored in a wood Ever-Normal Granary bin. Hutchinson, Kans. September, 1944.

Number hours after fumigation	Percent mortality of insects in check boxes			
	6' level	3' level	Floor	Average
1	100	69.2	27.4	70.0
2	100	97.2	76.7	93.3
3	100	98	94	97.6
4	100	100	99	99.5
5	100	98	92	96.4
6	100	100	97	99.4
7	100	99	100	99.7

A survey of the grain storage facilities on the farms in Reno County, Kansas, disclosed that many of the granaries are quite loosely constructed. Some are only single-walled structures, which not only allow water to enter, thus causing spoilage, but also make it difficult to create and hold a lethal concentration of fumigant for even a short period of time. Under such conditions greatly increased dosages of fumigant would be required or steps can be taken before filling the bin to improve its tightness.

In order to test the value of lining bins with reinforced paper, the walls of one bin in a two-bin farm granary were lined with Sisalkraft paper, the material being furnished through the cooperation of the Sisalkraft Company. The other bin was left unlined as a check. After filling with 1944 wheat, these bins were then given two fumigations as indicated in table 7.

Table 7: -- Effect of paper lining on the efficiency of fumigants in a farm granary. Reno County, Kansas. 1944.

Fumigant	Dosage Gals/1000 bu.	Percent mortality in check boxes: Lined bin	Percent mortality in check boxes: Unlined bin
Ethylene dichloride 75% carbon tetrachloride 25%	6	84	61
Carbon tetrachloride	3	87.5	47.5

It may be seen from the above table that lining a granary with a fiber-reinforced Kraft paper increases the effectiveness of fumigation from 23 to 40 percent on the basis of these two tests.

Insect Repellent Properties of Chemical Dusts when Mixed with Wheat*

In experimental work with dusts used to protect seed from insect attack it was noticed that seed treated with some of these appeared to repel insects. In order to further investigate this property, the following experiment was conducted.

Small, wooden, open top boxes, 6" x 6" x 6", of approximately 2000 gram capacity, were filled with wheat treated with magnesium oxide, Almicide, and DDT and placed in a bin of heavily infested grain. After being thus exposed to infestation for one month, the grain from each box was sifted and the number of living and dead insects counted. A record of the results of this test is given in table 8.

Whereas the infested grain in the bin contained an abundance of the rice weevil, the cadelle, the confused flour beetle, red flour beetle, lesser grain borer, small-eyed flour beetle, and flat grain beetle, practically the only beetles that invaded the boxes of treated wheat were the small-eyed flour beetle and the flat grain beetle.

Two of the dusts, magnesium oxide and Almicide, showed excellent repellent and killing properties. DDT, however, while demonstrating excellent killing properties, did not repel the insects, as the total number of live and dead insects in the boxes of wheat treated with it exceeded even those in the check boxes of untreated wheat.

In one test lot the grain was left untreated but the inside walls of the box were sprayed with a 5% solution of DDT in deobase oil. Enough of the spray was used to insure a complete coverage of the walls. Insects entering the wheat were forced to crawl over a portion of the treated walls of the box. This treatment gave a fairly good protection.

One significant feature not shown in the tabular results is the fact that only an occasional rice weevil was found in any of the treated boxes, whereas a considerable number were found in the check boxes. At various times it was noted that the rice weevil appeared to avoid all of the treated boxes. The same is true of the cadelle. Eight larvae were found in the check box while the treated boxes were entirely free of cadelle.

Table 8:--Repellent effect of various dusts on wheat to stored grain insects

Treatment and dosage	Number live insects	Number dead insects
MgO_2 -- 0.2% -- mixed with wheat	17	217
DDT (Conc.) -- 0.01% -- mixed with wheat	215	10822
DDT (Conc.) -- 0.02% -- mixed with wheat	171	12467
DDT — 5% in deobase -- inside of box only	887	2092
Almicide -- 0.2% -- mixed with wheat	17	2156
Check	3461	291

* - Contributed by R. T. Cotton and J. C. Frankenfeld, U. S. Department of Agriculture, Bureau of Entomology and Plant Quarantine.

Effect of DDT upon Stored Grain Insects

In view of the excellent results obtained in preliminary tests with DDT concentrate as a seed protectant, further tests were conducted with both the concentrated DDT powder and a 3% mixture of DDT and pyrophyllite.

In the first of these tests, dosages of 0.005%, 0.025%, and 0.05% DDT concentrate by weight were mixed with wheat. Five hundred gram lots of wheat with a 12.5% moisture content were weighed out into quart mason jars. The DDT powder was added and thoroughly mixed with the grain, after which the grain was exposed to insect attack. Eight species of stored grain insects as listed in table 9 were included in these tests. One hundred adults of each species were used per test except the cadelle and Indian meal moth of which only 25 larvae were used.

After one week the insects were removed from the wheat, and the percentage mortality determined. It will be noted that except for the cadelle larvae and the granary weevil adults, 100% kill was obtained with all three dosages. In the case of the granary weevil, 90 and 93% kills were obtained with dosages of 0.005% and 0.025% DDT after the first week, but after two weeks the mortality was complete. The cadelle is one species which seems to be resistant to this chemical. After five weeks, the percentage of kill for this species was 24, 52, and 80%, for dosages of 0.005, 0.025, and 0.05% respectively. No reproduction of any species in any of the tests took place.

In the second series of tests, a mixture of 3% DDT and pyrophyllite was used. In this series six species of insects were used. Data indicating the effect of this mixture on these insects over a period of 3 weeks are given in table 10. Dosages of 0.1%, 0.05%, and 0.01% by weight of the mixture were used together with a 0.1% dosage of pyrophyllite alone. Again, as in the first test, 100 adult insects of each species were used, with the exception of the cadelle.

Table 9: -- Insecticidal action of DDT concentrate mixed with wheat. After one week.

Insect used	Percentage kill with dosage of 0.005% by weight	0.025% by weight	0.05% by weight	Check
Cadelle larvae*	8	8	28	0
Rust red flour beetle	100	100	100	1
Confused flour beetle	100	100	100	0
Lesser grain borer	100	100	100	4
Sawtoothed grain beetle	100	100	100	1
Granary weevil**	90	93	100	0
Indian meal moth larvae	100	100	100	0
Rice weevil	100	100	100	0
*After five weeks--cadelle	24	52	80	0
**After two weeks--granary weevil	100	100		0

Table 10: -- Insecticidal action of a mixture of 3% DDT in pyrophyllite when mixed with wheat.

Insect used	Percentage of kill obtained with a 3% mixture of DDT and pyrophyllite									0.1% pyrophyllite alone after			Check		
	0.1% by weight after			0.05% by weight after			0.01% by weight after								
	1 Week	2 Weeks	3 Weeks	1 Week	2 Weeks	3 Weeks	1 Week	2 Weeks	3 Weeks	1 Week	2 Weeks	3 Weeks	1 Week	2 Weeks	3 Weeks
Rice weevil	100			100			52	91	98	2			2		
Confused flour beetle	89	100		54	100		9	31	65	1	4	9	1	1	2
Granary weevil	71	98	99	32	99	100	47	86	89	7	10	21	1	19	19
Cadelle	60	70	80	40	60	80	0	10	40	10	10	10	0	0	0
Sawtoothed grain beetle	100			97	100		36	56	65	10	31	44	10	13	15
Lesser grain borer	100			100			35	84	92	13	27	28	11	20	30

Effect of Magnesium Oxide, Almicide, and DDT on the Germination of Wheat

Magnesium oxide, Almicide, and DDT, when mixed with seed wheat in certain proportions have recently been shown to be highly effective in protecting it from the attack of many of the common grain infesting insects. In order to determine whether or not these dusts would have any effect on the germination of seed, the following series of tests were conducted.

Samples of wheat of 12, 14, and 16% moisture content were treated with dosages of the three dusts sufficiently high to insure a good kill of insects. The various lots of wheat, stored in tightly sealed quart glass jars were sampled each month for 4 months and tested for germination. Table 11 contains data indicating the changes in viability of all samples over a 4-month period.

Twelve and 14% moisture wheat showed no appreciable loss in germination over the 4-month period regardless of the treatment. In fact, in some cases a slight increase in percent germination was observed.

Wheat with a moisture content of 14% or more will show a fairly rapid loss in viability when stored at room temperature. This is indicated by the data of table 11 which show that the germination of untreated 14% wheat was reduced in 4 months from 88% to 75%.

In the 16% moisture series, a considerable reduction in viability occurred after 2 months in the wheat treated with Almicide and DDT, whereas the wheat treated with magnesium oxide showed but a slight reduction in viability after 2 month's storage.

It is possible that these dusts possess some value as germicides. The tests are being continued to determine this point.

Table 11: -- Effect of various dusts on the germination of wheat.

Treatment	Percent moisture wheat	Percentage of germination after: One Month	Two Months	Three Months	Four Months
MgO_2 -- 0.05%	12	92	92	90	88
do -- 0.1%	12	90	92	90	93
do -- 0.2%	12	89	93	90	94
do -- 0.05%	14	88	91	85	86
do -- 0.1%	14	90	90	87	84
do -- 0.2%	14	93	87	92	83
do -- 0.2%	16	92	84		
DDT (Conc.) -- 0.05%	12	91	95	93	86
do -- 0.1%	12	91	88	90	90
do -- 0.2%	12	90	90	90	95
do -- 0.2%	14	93	84		
do -- 0.2%	16	89	74		
Almicide -- 0.2%	14	95	85		
do -- 0.2%	16	94	69		
Check	12	87	86	93	87
do	14	88	82	87	75

Effect of Common Grain Fumigants on Baking Qualities of Wheat*

In order to determine whether or not some of the common grain fumigants would effect the baking qualities of wheat, samples were fumigated for 1 week in tightly closed jars with dosages of 50 pounds of carbon disulfide, carbon tetrachloride, carbon disulfide-carbon tetrachloride 1-4 mixture, and trichloroethylene per 1,000 bushels.

After 2 weeks aeration, the various wheat samples were milled and baked with the results indicated in table 19 of Report No. 12. A reduction in loaf volume was noted as a result of fumigation with carbon tetrachloride, probably due to retention of the chemical.

After 10 weeks aeration, the various samples were again milled and baked with the results indicated in table 11. It is evident that all samples were normal and no bad effects resulted from the various treatments.

* - R. T. Cotton and J. C. Frankenfeld in cooperation with the Milling Department, Kansas State College.

Table 11: -- Milling and baking values of wheat fumigated with various chemicals for one week and aerated for 10 weeks before milling.

Fumigant used	Dosage per 1,000 bushels	Flour yield	Flour protein	Flour absorption	Mixing time Min.	Mixing time Sec.	Loaf volume	Grain	Crumb color	Odor
Untreated check		72.5	12.60	65	3	0	795	80-o	85cy	Normal
Carbon disulfide	50 lbs.	72.5	11.4	63	3	0	808	80-o	85cy	do
Carbon tetrachloride	50 lbs.	74.5	11.55	63	2	2	808	82-o	85cy	do
Trichloroethylene	50 lbs.	74.5	12.00	64	2	7	823	82-o	85cy	do
CS_2 - CCl_4 mix	50 lbs.	72.5	12.10	64	2	5	818	80-o	85cy	do

Effect of Fumigants on Germination and Baking and Milling Qualities of Wheat

One year ago experimental work was started to determine the effect of fumigation and subsequent storage with and without aeration on the germination and milling and baking qualities of wheat of 10.5, 12.5 and 14% moisture content. Wheat samples at each moisture level were fumigated with normal dosages of all the commonly used grain fumigants. One portion of each fumigated lot was then aerated while another portion was held without aeration. In addition two lots of each moisture variant wheat were fumigated with excessive dosages of methyl bromide and chloropicrin in order to kill the germination immediately. Germination tests were run on all samples at monthly intervals and baking tests were made a regular intervals or when significant changes in viability of the grain occurred.

Germination data given in tables 12, 13, and 14 indicate changes in viability of 10.5, 12.5, and 14.0% moisture wheat as affected by fumigation with common grain fumigants and subsequent storage of aerated and non-aerated samples for 12 months.

In the 10.5% moisture wheat no significant loss in viability occurred during the 12-month period of storage where the grain was aerated after fumigation, with the exception of the samples fumigated with excess dosages of methyl bromide and chloropicrin. In the case of the samples of wheat that were not aerated, normal dosages of fumigants containing chloropicrin and methyl bromide caused a significant drop in germination.

With the 12.5% moisture wheat all samples showed a loss in viability after 12 months. In the aerated samples loss in viability was more pronounced in the samples fumigated with Cyanogas and with mixtures containing methyl bromide, chloropicrin, and carbon disulfide. In the non-aerated samples loss of viability was pronounced in all cases, but most severe in the case of the samples fumigated with mixtures containing methyl bromide or chloropicrin. In most cases significant changes in viability did not occur until the 11th month. It seems likely that the particular wheat used in this series did not possess very good keeping qualities since the tendency to deteriorate after 10 months in storage showed up in all samples at the same time.

With the 14% moisture wheat little loss in viability occurred in the aerated samples with the exception of those fumigated with mixtures containing chloropicrin or methyl bromide, or with excessive dosages of methyl bromide or chloropicrin. In the non-aerated samples germination damage occurred in samples fumigated with carbon disulfide and with mixtures containing carbon disulfide, Ethide, and chloropicrin.

Table 12: -- Changes in viability of 10.5% moisture wheat over 12 month period as affected by fumigation with common grain fumigants and subsequent storage of aerated and non-aerated samples.

Fumigant	Dosage per 1,000 bushels	Treatment	Percent germination at end of month number 1	2	3	4	5	6	7	8	9	10	11	12
Check			96	94	97	98	94	95	97	98	94	99	86	89
Dowfume 75	6 gals.	Aerated	95	93	92	93	95	96	98	96	95	96	87	90
do	do	Non-aerated	96	95	94	92	95	96	95	94	93	95	89	88
Cyanogas	15 lbs.	Aerated	97	96	98	96	96	95	95	94	98	92	89	86
do	do	Non-aerated	97	96	99	92	95	97	94	96	97	96	93	92
Carbon disulfide	3 gals.	Aerated	95	96	97	94	95	95	94	94	95	94	94	89
do	do	Non-aerated	95	94	96	95	89	96	96	95	95	94	91	88
CS_2 - CCl_4 mix	3 gals.	Aerated	97	98	97	92	97	96	94	95	92	95	88	90
do	do	Non-aerated	93	95	94	91	95	95	97	94	93	93	92	87
do	6 gals.	Aerated	95	97	90	95	95	94	95	96	95	92	89	88
do	do	Non-aerated	89	96	86	96	91	96	92	95	94	98	93	89
Ethide - CCl_4 mix	1 gal,	Aerated	96	95	96	93	98	94	94	93	97	97	90	81
do	do	Non-aerated	93	91	93	92	94	98	90	93	95	94	87	86
Chloropicrin-CCl_4 mix	2 gals.	Aerated	96	91	94	92	91	92	91	93	93	95	90	85
do	do	Non-aerated	76	82	85	84	84	89	82	87	80	83	74	57
Dowfume Br 10	2 gals.	Aerated	94	96	97	96	96	98	96	98	93	98	89	94
do	do	Non-aerated	91	87	97	84	90	91	90	94	91	93	84	77
Methyl bromide	40 lbs.	Aerated	2	2.4	3	5	4	6	4	3	5	5	2	3
Chloropicrin	40 lbs.	Aerated	3	3.2	2	2	3	4	4	3	1	4	1	3

Table 13: -- Changes in viability of 12.5% moisture wheat over 12 month period as affected by fumigation with common grain fumigants and subsequent storage of aerated and non-aerated samples.

Fumigant	Dosage per 1,000 bushels	Treatment	Percent germination at end of month number											
			1	2	3	4	5	6	7	8	9	10	11	12
Check			98	95	94	94	96	95	94	94	92	95	85	74
Dowfume 75	6 gals.	Aerated	94	95	96	94	92	94	93	94	88	98	85	83
do	do	Non-aerated	93	91	96	91	89	92	95	89	89	89	72	58
Cyanogas	15 lbs.	Aerated	94	96	97	94	91	92	92	93	93	97	82	72
do	do	Non-aerated	92	96	96	92	93	90	93	91	92	90	82	63
Carbon disulfide	3 gals.	Aerated	94	94	95	95	94	96	92	96	93	94	88	81
do	do	Non-aerated	87	89	88	84	76	83	89	81	84	92	48	46
CS_2 - CCl_4 mix	3 gals.	Aerated	95	92	94	95	91	92	96	94	94	93	87	85
do	do	Non-aerated	95	95	95	95	95	93	95	94	92	91	82	71
do	6 gals.	Aerated	95	95	94	96	91	92	94	93	96	93	86	73
do	do	Non-aerated	87	90	92	90	83	86	93	89	85	93	63	53
Ethide - CCl_4 mix	1 gal.	Aerated	95	92	92	95	92	90	92	94	95	93	88	76
do	do	Non-aerated	87	87	90	82	83	85	89	86	81	87	53	47
Chloropicrin-CCl_4 mix	2 gals.	Aerated	89	92	94	92	90	89	89	89	91	96	84	70
do	do	Non-aerated	78	86	76	74	77	74	84	77	80	78	55	39
Dowfume Br 10	2 gals.	Aerated	93	88	94	91	93	90	92	89	91	95	82	68
do	do	Non-aerated	75	84	82	83	70	71	76	64	84	81	43	36
Methyl bromide	40 lbs.	Aerated	0	0	0	0	0	0	0	0	0	0	0	0
Chloropicrin	40 lbs.	Aerated	10	4	11	9	9	9	9	7	8	9	10	6

Table 14: -- Changes in viability of 14.0% moisture wheat over 12 month period as affected by fumigation with common grain fumigants and subsequent storage of aerated and non-aerated samples.

Fumigant	Dosage per 1,000 bushels	Treatment	Percent germination at end of month number											
			1	2	3	4	5	6	7	8	9	10	11	12
Check			89	89	95	92	88	90	82	44*				
Dowfume 75	6 gals.	Aerated	93	97	95	93	92	94	94	95	96	91	89	87
do	do	Non-aerated	90	94	92	89	84	91	93	91	86	85	81	80
Cyanogas	15 lbs.	Aerated	95	95	95	93	91	92	94	95	94	91	90	89
do	do	Non-aerated	92	95	95	93	96	94	97	94	89	85	92	83
Carbon disulfide	3 gals.	Aerated	93	94	94	93	89	94	94	94	93	93	91	94
do	do	Non-aerated	77	81	87	66	64	60	82	77	68	49	33	41
CS_2 - CCl_4 mix	3 gals.	Aerated	92	95	96	92	92	94	94	93	96	93	94	92
do	do	Non-aerated	86	90	86	84	82	91	95	90	84	74	68	65
do	6 gals.	Aerated	93	96	98	89	89	93	94	93	95	92	87	89
do	do	Non-aerated	79	94	84	66	76	86	81	89	76	59	59	54
Ethide - CCl_4 mix	1 gal.	Aerated	93	95	94	89	89	92	96	94	96	91	91	94
do	do	Non-aerated	82	91	82	64	67	73	76	79	79	50	42	44
Chloropicrin-CCl_4 mix	2 gals.	Aerated	64	66	77	65	67	79	68	68	80	65	68	77
do	do	Non-aerated	39	38	38	33	37	39	36	35	41	32	31	37
Dowfume Br 10	2 gals.	Aerated	92	92	93	90	91	93	94	93	95	76	82	85
do	do	Non-aerated	61	82	77	49	50	39	56	60	52	29	35	30
Methyl bromide	40 lbs.	Aerated	0	0	0	0	0	0	0	0	0	0	0	0
Chloropicrin	40 lbs.	Aerated	10	11.1	20	13	20	7	14	21	12	5	11	6

* - Reduction in germination due to insect damage.

Effect on Baking

The effect of fumigation and subsequent storage for 12 months on baking quality is indicated by the data of table 15. Complete baking tests were made only on the 14% moisture series since this type of wheat is most difficult to store successfully and damage to germination from fumigation likely to be more pronounced.

The data of table 15 indicate that no significant differences in baking values resulted from the various treatments after 12 months storage regardless of whether or not the germination of the wheat was affected by fumigation. Flour made from wheat with zero germination for one year, showed no loss in baking value as compared with flour made from untreated wheat stored for the same period.

This data refutes the old theory that viability of the seed is a criterion of baking quality.

Table 15:--Effect of fumigation and subsequent storage on baking quality of wheat. Baking tests after 12 months storage.

% Moisture of wheat	Fumigant	Dosage per 1000 bushels	Treatment	Flour protein	Flour absorption	Mixing time Min.	Mixing time Sec.	Loaf volume	Grain	Crumb color	Odor
10.5	Check			14.25	67	2	0	858cc	82-o	85cy	-
10.5	Methyl bromide	40 lbs.	Aerated	13.50	66	2	0	828	82-o	85cy	++
10.5	Chloropicrin	40 lbs.	Aerated	13.80	66	2	0	835	82-o	85cy	+
12.5	Check			11.20	63	2	7	710	82-o	85cy	-
12.5	Methyl bromide	40 lbs.	Aerated	12.15	64	2	7	705	82-o	85cy	++
12.5	Chloropicrin	40 lbs.	Aerated	11.25	63	3	0	770	82-o	85cy	++
14	Check			10.7	63	2	0	785	86-o	88cw	-
14	Dowfume 75	6 gals.	Aerated	10.7	63	2	0	778	86-o	88cw	++
14	do	do	Non-aerated	10.6	63	2	0	800	86-o	88cw	-
14	Cyanogas	15 lbs.	Aerated	10.7	63	2	0	775	86-o	88cw	+++
14	do	do	Non-aerated	10.7	63	2	0	805	86-o	88cw	+
14	Carbon disulfide	3 gals.	Aerated	10.8	63	2	0	775	86-o	88cw	+
14	do	do	Non-aerated	10.7	63	2	0	795	86-o	88cw	-
14	CS_2 - CCl_4 mix	3 gals.	Aerated	10.75	63	2	0	808	86-o	88cw	-
14	do	do	Non-aerated	10.75	63	2	0	810	86-o	88cw	-
14	do	6 gals.	Aerated	10.75	63	2	0	783	86-o	88cw	-
14	do	do	Non-aerated	10.7	63	2	0	798	86-o	88cw	-
14	Ethide - CCl_4 mix	1 gal.	Aerated	10.75	63	2	0	785	86-c	88cw	-
14	do	do	Non-aerated	10.75	63	2	0	788	86-o	88cw	-
14	Chloropicrin-CCl_4 mix	2 gals.	Aerated	10.9	63	2	0	807	86-o	88cw	-
14	do	do	Non-aerated	10.65	63	2	0	798	86-o	88cw	-
14	Dowfume Br 10	2 gals.	Aerated	10.7	63	2	0	780	86-o	88cw	-
14	do	do	Non-aerated	10.60	63	2	0	808	86-o	88cw	-
14	Methyl bromide	40 lbs.	Aerated	11.0	63	2	0	778	86-o	88cw	+++
14	Chloropicrin	40 lbs.	Aerated	10.8	63	2	0	805	86-o	88cw	++

Footnote: Number of crosses in last column indicates severity of odor.

Effect of Temperature, Moisture, and Dockage on Tribolium castaneum

Tribolium castaneum, commonly known as the red flour beetle, is one of the so-called "bran bugs". Although it is referred to as a flour beetle it is also frequently found in whole grain, and is one of the most important of the "bran bugs" infesting stored grain. As with its near relative, T. confusum, little is known of the effect of temperature, moisture and dockage in grain upon the survival and reproduction of this insect.

In order to definitely establish the effects of temperature, grain moisture, and dockage on this insect, a series of tests were started in which these three factors were controlled. Twenty newly transformed adult beetles, 10 females and 10 males, were confined in Erlenmeyer flasks with 300 grams of wheat. The moisture content of the wheat was adjusted to the desired level, and was kept constant by forcing through it compressed air conditioned by passage through a sulfuric acid solution, the density of which conformed to the relative humidity required to hold the wheat at the desired moisture. This method has proved very successful in maintaining a constant humidity and thus a constant moisture condition of the grain. Over periods of 20 weeks the moisture content of the wheat is still within the range of experimental error, of the moisture content at the start of the test. Occasional testing of the specific gravity of the sulfuric acid is necessary so that proper adjustment can be made to the solution if necessary. However, only occasionally, due to extreme variations of the relative humidity of the atmosphere, is it necessary to adjust the specific gravity of the sulfuric acid during the period covered by a given test.

Constant temperatures were maintained by means of thermostatically controlled electric incubators. With our equipment we are able to hold the temperature constant to within $\pm$ 1°F.

Dockage was added in the form of whole ground wheat. The reason for using whole ground wheat is to obtain a dockage that is uniform throughout, thus enabling us to make our records more comparable. The wheat used in these tests was first screened over a 10-mesh wire screen, removing all cracked kernels and dust, normally found in the grain. Dockage was then added to the amount desired. In these tests we are using moisture variants of 9, 12, and 15%, and dockage variants of 0, 0.5, 1.0, 2.0, 4.0, and 8.0%.

The first series of these tests with T. castaneum is still in progress. Data relative to the percentage of survival and the number of progeny recovered as pupae are herewith reported on. It will be noted from table 16 that there is little significant difference in the percentage of survival over a period of 8 weeks at 90° F. at the various moisture levels. What differences exist cannot be attributed to any variation in the factors under control. There is, however, an indication of a higher percentage of survival as the moisture content of the wheat is increased. A fact which will probably become more obvious as the length of time that these tests are in progress is increased.

With regard to the rate of reproduction of this insect there is a decided increase as the amount of dockage is increased for a given moisture level. And, reproduction also increases as the moisture content of the grain is increased.

In the 15% moisture series, the lots containing 2, 4, and 8% dockage, have not been in progress as long as the three lots containing clean wheat, 0.5 and 1% dockage. For some unknown reason, probably mold growth, all adults and immature progeny in these cultures died during the first three weeks in which the tests were in progress. A fresh supply of food with new adults was prepared, and these lots have been in progress for 4 weeks with the results as listed in table 16.

Table 16: — Percentage of survival of the rust red flour beetle in 9, 12, and 15% moisture wheat with varying amounts of dockage and the total number of pupae recovered. Temperature--90° F.

Food media	Percentage of survival after								Number of pupae recovered
	1 Week	2 Weeks	3 Weeks	4 Weeks	5 Weeks	6 Weeks	7 Weeks	8 Weeks	
9% Wheat									
Clean wheat	100	100	100	100	100	100	90	80	31
Same plus 0.5% dockage	85	80	80	80	80	75	70	70	45
Same plus 1.0% dockage	100	100	100	100	100	100	100	100	118
Same plus 2.0% dockage	95	95	90	90	90	90	90	85	111
Same plus 4.0% dockage	100	95	95	95	95	95	95	95	174
Same plus 8.0% dockage	95	95	90	85	85	85	75	70	299
12% Wheat									
Clean wheat	100	100	100	100	100	100	100	100	194
Same plus 0.5% dockage	100	100	95	95	95	95	95	95	318
Same plus 1.0% dockage	100	100	95	95	90	90	85	80	333
Same plus 2.0% dockage	95	95	95	95	95	95	95	95	345
Same plus 4.0% dockage	100	100	100	100	100	100	100	100	437
Same plus 8.0% dockage	100	100	100	95	95	95	95	95	724
15% Wheat									
Clean wheat	100	100	100	100	100	100	100	100	353
Same plus 0.5% dockage	100	100	100	100	100	100	100	100	343
Same plus 1.0% dockage	100	100	100	100	100	100	100	100	369
Same plus 2.0% dockage	100	100	100	100					114
Same plus 4.0% dockage	100	100	100	100					206
Same plus 8.0% dockage	95	95	95	95					391

Effect of Temperature and the Moisture Content of Wheat upon the Survival and Reproduction of the Granary and Rice Weevil

The series of tests herewith reported on were conducted at constant temperatures of 90 and 60° F., with wheat of moisture contents of 9, 10, 11, 12, 13, and 14%. Each moisture variant wheat was run in duplicate, and the results of the percentages of survival at 90° F. over a period of 19 weeks are summarized in table 17. For the lower level moisture wheat (9 to 11%), the percentage of survival increases as the moisture content of the wheat is increased, with practically no significant differences between the granary or rice weevil. Not so great a difference in percentage of survival is noted in the 12, 13, and 14% moisture wheat, although for both species a higher percentage of survival is noted in the 13 and 14% moisture wheat than in the 12% wheat. The percentage of survival of granary weevil is greater than that of the rice weevil in all three moisture variants. Whether this is due entirely to the effect of temperature and moisture is doubtful. In all probability it is due to the fact that the granary weevil adults usually live longer than do the adults of the rice weevil.

At 90° F. the life span of both species is greatly reduced in the 9, 10, and 11% moisture wheat, and no reproduction occurred in the case of the granary weevil. A small amount of reproduction took place in the case of the rice weevil in the 10 and 11% moisture wheat, but no reproduction was obtained in the 9% wheat. This is contrary to results obtained in earlier tests, where we obtained reproduction of both species in 9% wheat at this temperature. In this series of tests, the 9% moisture lots were repeated three times giving 6 replicated tests. The results were essentially the same as the two tests recorded in the accompanying tables. That is, all adults were dead within a period of 3 to 5 weeks, and no reproduction was obtained.

In the 12, 13, and 14% moisture lots at 90° F., the average total reproduction increases as the moisture content of the wheat is increased. This is true for both the granary and rice weevil. Variations as noted between the two lots containing the same moisture content wheat are due to variations in the respective survival of adults.

Table 17:--Percentage of survival of the granary and rice weevil in 9, 10, 11, 12, 13, and 14% moisture wheat at 90° F.

Insect used	Percentage of survival after 1 Week	3 Weeks	5 Weeks	7 Weeks	9 Weeks	11 Weeks	13 Weeks	15 Weeks	17 Weeks	19 Weeks	Total No. of progeny produced	Ave.
9% Wheat												
Granary weevil	67	13	4	0							0	
do	54	20	6	0							0	0
Rice weevil	27	4	0								0	
do	8	1	0								0	0
10% Wheat												
Granary weevil	92	85	38	3	0						0	
do	90	79	41	18	6	0					0	0
Rice weevil	79	65	11	7	0						29	
do	52	28	16	11	3	0					63	46
11% Wheat												
Granary weevil	95	85	68	23	12	0						
do	97	94	82	52	29	0						
Rice weevil	94	89	70	49	32	23	6	4	0		24	
do	72	57	45	39	30	22	4	2	0		16	20
12% Wheat												
Granary weevil	94	89	79	66	38	29	14	8	0		1052	
do	100	90	82	71	50	44	35	11	2	0	1250	1151
Rice weevil	100	95	85	74	43	25	16	5	0		2233	
do	93	84	79	64	45	30	15	1	0		1860	2047
13% Wheat												
Granary weevil	99	97	91	82	73	60	46	22	14	8	2193	
do	97	92	86	76	63	58	50	30	12	9	1061	1627
Rice weevil	99	96	63	59	22	15	13	7	2	0	3230	
do	98	88	15	15	13	7	6	4	0		1242	2236
14% Wheat												
Granary weevil	99	90	78	72	66	55	43	22	14	6	3194	
do	100	91	84	72	63	54	44	36	22	15	2272	2733
Rice weevil	99	95	61	54	49	42	34	18	11	6	3934	
do	100	78	12	11	9	7	6	4	0		1831	2882

The data of tables 18 and 19 show the biweekly reproduction of granary and rice weevil for the various moisture wheats at 90° F. At this temperature reproduction in all moisture variant wheats is greatest during the first seven weeks, dropping off substantially after this time and terminating after the 15th week.

In another series of tests, at which the temperature was held constant at 60° F. the percentage of survival again increases as the moisture content of the wheat is increased. This series of tests has been in operation for 13 weeks and the results of biweekly examinations are listed in table 20. At all moisture variant wheats, the percentage of survival of the granary weevil is decidedly greater than that of the rice weevil.

Reproduction records for this series are not complete, but a small amount of reproduction is being obtained in the case of the rice weevil, in the 13 and 14% moisture wheat. No reproduction of the granary weevil at any moisture level has been obtained for this temperature to date.

Table 18:--Summary of reproduction of rice weevil in 9, 10, 11, 12, 13, and 14% moisture wheat at 90° F.

Moisture content of wheat	Number of progeny produced during 1st Week	2nd & 3rd Week	4th & 5th Week	6th & 7th Week	8th & 9th Week	10th & 11th Week	12th & 13th Week	14th & 15th Week	16th & 17th Week	18th & 19th Week	Total
9%	0	0	0	0	0						0
9%	0	0	0	0	0						0
10%	0	0	0	0	0						0
10%	0	0	0	0	0						0
11%	0	0	0	23	0	0	0	0	0		23
11%	0	0	0	14	0	0	0	0	0		14
12%	416	668	529	469	110	40	0	0	0		2233
12%	301	394	382	427	186	125	44	1			1860
13%	441	678	742	710	216	20	22	1			3230
13%	280	118	374	329	82	41	17	1	0		1242
14%	713	990	822	720	433	194	36	16	0	0	3934
14%	694	708	188	189	41	0	11	0	0		1831

Table 19:--Summary of reproduction of granary weevil in 9, 10, 11, 12, 13, and 14% moisture wheat at 90° F.

Moisture content of wheat	Number of progeny produced during 1st Week	2nd & 3rd Week	4th & 5th Week	6th & 7th Week	8th & 9th Week	10th & 11th Week	12th & 13th Week	14th & 15th Week	16th & 17th Week	18th & 19th Week	Total
9%	0	0	0	0	0	0	0	0	0	0	0
9%	0	0	0	0	0	0	0	0	0	0	0
10%	0	0	0	0	0	0	0	0	0	0	0
10%	0	0	0	0	0	0	0	0	0	0	0
11%	0	0	0	0	0	0	0	0	0	0	0
11%	0	0	0	0	0	0	0	0	0	0	0
12%	320	329	230	126	40	7	0	0	0	0	1052
12%	373	391	220	188	51	19	8	0	0	0	1250
13%	592	478	618	376	67	21	29	10	1	0	2193
13%	354	269	229	159	32	9	7	2	0	0	1061
14%	780	752	699	493	294	138	38	0	0	0	3194
14%	612	520	445	351	190	12	99	39	9	0	2272

Table 20: -- Percentage of survival of the granary and rice weevil in 9, 10, 11, 12, 13, and 14% moisture wheat at 60° F.

Insect used	Percentage of survival after 1 Week	3 Weeks	5 Weeks	7 Weeks	9 Weeks	11 Weeks	13 Weeks
9% Wheat							
Granary weevil	98	84	74	68	68	68	40
do	98	84	80	76	76	76	30
Rice weevil	98	14	10	8	6	6	0
do	96	12	6	2			
10% Wheat							
Granary weevil	98	92	92	88	88	84	62
do	96	90	86	78	78	78	62
Rice weevil	98	88	88	82	80	72	20
do	100	84	84	84	78	78	28
11% Wheat							
Granary weevil	100	96	96	96	96	92	86
do	100	100	100	100	100	94	88
Rice weevil	100	90	88	82	78	76	62
do	100	90	84	78	76	74	54
12% Wheat							
Granary weevil	100	96	94	86	84	82	74
do	100	100	96	94	94	94	82
Rice weevil	100	96	94	90	90	78	32
do	100	98	94	90	88	80	34
13% Wheat							
Granary weevil	100	100	100	98	98	96	94
do	100	100	100	96	96	96	96
Rice weevil	98	94	86	86	84	74	66
do	98	94	88	88	82	76	70
14% Wheat							
Granary weevil	100	100	100	98	96	96	92
do	98	98	94	94	94	94	92
Rice weevil	98	98	98	96	90	86	80
do	96	96	96	96	90	84	76